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Mass equations and merchantability factors for Ontario softwoods

I.S. Alemdag

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PETAWAWA NATIONAL FORESTRY INSTITUTE

The Petawawa National Forestry Institute was formed on April 1, 1979, as the result of an amalgamation of the former Petawawa Forest Experiment Station, which had existed for more than 60 years, with the Ottawa-based Forest Management and Forest Fire Research institutes.

In common with the rest of the Canadian Forestry Service, the Petawawa National Forestry Institute has as its objective the promotion of better management and wiser use of Canada's forest resource to the economic and social benefit of all Canadians. Because it is a national institute, particular emphasis is placed on research into problems that transcend regional boundaries or that require special expertise and expensive equipment that cannot be duplicated in CFS regional establishments. Such research is often performed in close cooperation with staff of the regional centres or provincial forest services.

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FOREWORD

ENFOR is the acronym for the Canadian Government's ENergy from the FORest (ENergie de la FORêt) program of research and development aimed at securing the knowledge and technical competence to facilitate, in the medium to long-term, a greatly increased contribution from forest biomass to our nation's primary energy production. This program is part of a much larger federal government initiative to promote the development and use of renewable energy as a means of reducing dependence on petroleum and other non-renewable energy sources.

The Canadian Forestry Service (CFS) administers the ENFOR Biomass Production program component which deals with such forest-oriented subjects as inventory, harvesting technology, silviculture and environmental impacts. (The other component, Biomass Conversion, deals with the technology of converting biomass to energy or fuels, and is administered by the Renewable Energy Branch of the Department of Energy, Mines and Resources). Most Biomass Production projects, although developed by CFS scientists in the light of ENFOR program objectives, are carried out under contract by forestry consultants and research specialists. Contractors are selected in accordance with science procurement tendering procedures of the Department of Supply and Services. For further information on the ENFOR Biomass Production program, contact

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or a CFS research laboratory.

This report is based on ENFOR project P-179 which was carried out under contract (DSS File No. KL011-1-0257) by the Canadian Forestry Service and the Horton Forestry Services Ltd. in 1981 and 1982.

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MASS EQUATIONS AND MERCHANTABILITY FACTORS FOR ONTARIO SOFTWOODS

Abstract

Equations for estimating biomass of single trees by their major components were developed for ten Ontario softwood species. These equations, based on diameter at breast height outside bark and total tree height, directly estimate the ovendry mass. Equations for predicting ovendry mass percentages of the merchantable and unmerchantable components of the stem were also developed. These are based on merchantable top diameter and diameter at breast height outside bark, or merchantable height and total tree height.

Résumé

Des équations estimant la biomasse d'arbres par leurs composantes majeures ont été développées pour dix espèces résineuses de l'Ontario. Basées sur le diamètre à hauteur de poitrine avec écorce et sur la hauteur totale de l'arbre, ces équations estiment directement la masse anhydre. Des équations prédisant les pourcentages de masse anhydre des parties marchandes et non-marchandes de la tige ont aussi été développées. Celles-ci sont baseés sur la diamètre marchand au fin bout et sur le diamètre à hauteur de poitrine avec écorce ou sur la hauteur marchande et la hauteur totale de l'arbre.

INTRODUCTION

Aboveground-biomass estimation equations and merchantability factors were published previously for four of the major Ontario softwood species (Alemdag 1982a, b). Later, in order to complete the study, the same type of relationships were compiled for the remaining six softwood species of commercial importance in Ontario. The aim of the present report is to make this new information available, and at the same time to present equations and factors for the original four species in a comprehensive way, all under one cover.

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METHODS

Data collection

The data on the following four species were collected from natural stands in the Chalk River area, and in the Englehart Management Unit:

Jack pine (Pinus banksiana Lamb.)
Black spruce (Picea mariana (Mill.) B.S.P.)
White spruce (Picea glauca (Moench) Voss)
Balsam fir (Abies balsamea (L.) Mill.)

Additional sample tree data were collected[1] on the following six species in natural stands of Ontario's southern region

[1] The data on these six species were collected in 1981 and 1982, and on the previous four species in 1978, all by Horton Forestry Services Limited, Stouffville, Ontario, L0H 1L0, under Canadian Forestry Service ENFOR contracts.

(Stouffville, Napanee, Marmora), central region (Haliburton, Wilno, Petawawa, Parry Sound) and northern region (Aubrey Falls, Timagami, Atikokan):

Eastern white pine (Pinus strobus L.)
Red pine (Pinus resinosa Ait.)
Tamarack (Larix laricina (Du Roi) K. Koch)
Eastern white cedar (Thuja occidentalis L.)
Eastern red cedar (Juniperus virginiana L.)
Eastern hemlock (Tsuga canadensis (L.) Carr.).

These data, which were collected in accordance with instructions provided in a biomass manual (Alemdag 1980), contained the following information relevant to the study:

(i) Diameter at breast height outside bark (d),
(ii) Total tree height (h),
(iii) Merchantable top diameter outside bark (dm) at 1/3, 2/3 and 3/3 of the height at which a diameter of 9.1 cm occurs,
(iv) Merchantable height (hm) (height from ground level to the merchantable top diameter),
(v) Green mass (GM) and ovendry mass (OM) of:
  (a) main tree-components of stem wood, stem bark, live branches, and twigs plus needles for trees larger than 5.0 cm of d,
  (b) the whole tree for trees smaller than 5.1 cm of d, and for seedlings and saplings (for the purpose of this study, the seedlings and saplings are defined as woody plants smaller than or equal to 1.30 m of height),
  (c) stem wood and stem bark, separately, below and above a given merchantable top diameter,
  (d) stump wood and stump bark, separately, to a 30-cm stump height,
(vi) Basic wood density (i.e., ratio of ovendry mass to green volume) at breast height and at locations of merchantable top diameter.

Diameters were recorded in centimetres, heights in metres, masses in kilograms and wood densities in kg/m^3. The smallest measured top diameter was 9.1 cm. Stratified random sampling was applied and sample trees were taken, with even distribution over the full range of diameter classes of the species and over the full range of heights within diameter classes. Some statistics on the basic data can be seen in Table 1 (Appendix A) and Table 6 (Appendix B). The main tree-components, and merchantable and unmerchantable components, can be studied in Figure 1. Stump wood and stump bark were defined here as a part of the merchantable portion of the stem, but this was only for the purpose of analysis, as will be explained and demonstrated later.

Compilation and analysis

The method followed in constructing the equations for the biomass estimation of the main components of the six new species is the same as that of described in the publication of the first four species (Alemdag 1982a). That is, for trees of 5.1 cm and larger in d, ovendry mass of each component and of the whole tree, as well as dead branches of each species and the combination of all species, were expressed as a function of d^2h. The model used in the regression analysis was

$$OM = b_1 \cdot d^2h \qquad (1)$$

For trees with a d from 0.1 cm to 5.0 cm, only the ovendry mass of the whole tree, for all species combined, was formulated and the equation used was in the form

$$OM = b_0 + b_1 \cdot d^2h \qquad (2)$$

where OM, d and h are as given above.

Furthermore, based on these estimation equations, component, whole-tree,

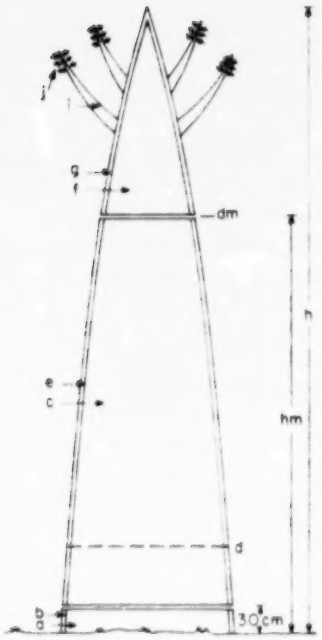

Figure 1. Diagram illustrating the main tree-components, and merchantable and unmerchantable components of the stem. a: stump wood, b: stump bark, c: net merchantable-stem wood, d: net merchantable-stem bark, e: top wood, f: top bark, g: live branches, h: twigs plus needles.

and dead-branch ovendry masses were expressed as percent of stem wood ovendry mass.

The basic wood density of each species, i.e., the ratio of ovendry mass to green volume, was calculated as being the arithmetic average of the densities measured at four locations along the stem.

In addition, ovendry mass/green mass ratios of four main components and of the whole tree were computed using the sums of observed mass values.

The merchantability factors or the biomass of merchantable and unmerchantable components of the stem were formulated using the same approach explained in detail in an earlier publication (Alemdag 1982b). That is, by using their percentage values, ovendry mass of the merchantable portion (wood and bark separately) and of the top (wood and bark together) were expressed using either the merchantable top diameter or the merchantable height. The models were:

$$OM\% = b_0 + b_1 \cdot (dm/d) + b_2 \cdot (dm/d)^2 \qquad (3)$$

$$OM\% = b_0 + b_1 \cdot (hm/h) + b_2 \cdot (hm/h)^2 \qquad (4)$$

where OM% is ovendry-mass percentage of wood or of bark of merchantable portion (hereinafter called merchantable-stem wood or merchantable-stem bark) below a given diameter or height, or ovendry-mass percentage of wood plus bark of top portion above a given diameter or height. The percentages in these models are expressed in terms of total stem mass. The other variables are as given before. In the foregoing models, owing to the logic followed in developing them, merchantable-stem wood includes stump wood, and merchantable-stem bark includes stump bark. Stump was studied independently of these three stem components in order to deduct its amount from the estimated merchantable-stem wood and merchantable-stem bark percentages. Net merchantable values were calculated in this fashion. After working with the individual species, the data from the ten species were combined to develop prediction equations for all softwoods together. Furthermore, the percentage distribution of mass in a stump of 30-cm height was calculated for various stump heights in order to be used with average stump values. This was done by a geometric method in which stump was considered as the frustum of a neiloid (Alemdag 1982b).

Wherever applicable, the suitability and performance of regression equations was judged by the values of the coefficient of determination (r^2) or multiple determination (R^2), and by the standard error of estimate as percent of the mean (SEE%).

RESULTS

The results of the analysis for estimating ovendry mass of the main tree components, namely, stem wood, stem bark, live branches and twigs plus needles, and of

the whole tree and dead branches, for trees larger than 5.0 cm of d are provided in Table 2 (Appendix A) for Equation 1. Also given in this appendix are the percentages of these ovendry masses with regard to stem wood ovendry mass (Table 3), the ratios of ovendry mass to green mass (Table 4), and the average basic wood densities (Table 5). As will be noted, the ovendry mass predictions of stem wood and of the whole tree are considerably better than those of the others in all species. It is important to note that the total of predicted ovendry mass values of four basic components is equal to predicted ovendry mass of the whole tree. The mass of dead branches is not considered a part of the whole tree mass. Equation coefficients for ovendry mass of the whole tree for all species combined, for trees with a d smaller than 5.1 cm were established as b_0 =0.250 and b_1 =0.016952. Seedlings and saplings of all these softwood species were found to contain the following average whole-tree ovendry masses:

Stems from 0.01 m to 0.30 m=0.008 kg
Stems from 0.31 m to 0.80 m=0.042 kg
Stems from 0.81 m to 1.30 m=0.153 kg

Coefficients for the prediction equations of the percentage values of merchantable-stem wood, merchantable-stem bark and top wood plus bark, together with the statistical data are given in Tables 7 and 8 (Appendix B) for Equations 3 and 4 respectively. The average stump values at 30-cm stump height (Table 9) and volume (and mass) percentage distributions at different stump heights (Table 10) are also provided in the same appendix. Prediction of percentages of merchantable-stem wood and of top wood plus bark can be made very accurately by employing either the dm/d or the hm/h equations. Merchantable-stem bark percentage estimations fare less well when compared with these two equations; however, they are also highly accurate within themselves. It should be noted that the percentage estimations of all these three merchantable components add up to 100.

APPLICATIONS

In practice, the above-developed equations will be used in the following manner:

1. Calculating ovendry mass of basic components from inventory data

   (a) Where tree dimensions together with total number of trees are available, Equation 1 (Table 2) will be used with d and h measurements of either individual trees or of the mean tree for trees larger than 5.0 cm of d, and Equation 2 will be used for trees with a d from 0.1 cm to 5.0 cm. For example, a balsam fir tree with d=21.4 cm and h=17.80 m has a stem wood mass of 101.4 kg, stem bark mass of 16.3 kg, live branches mass of 13.1 kg, twigs plus needles mass of 18.4 kg, the whole tree mass of 149.2 kg, and dead branches mass of 5.8 kg.

   (b) Where only the total stem volume inside bark is available, the basic wood density (Table 5) will be used to convert this volume into ovendry mass, and then the percentages of Table 3 will be employed to find ovendry mass of the other components. For example, a pure stand of balsam fir with 180 m^3/ha of volume contains 62 820 kg of stem wood, 10 114 kg of stem bark, 8 104 kg of live branches, 11 433 kg of twigs plus needles, 92 471 kg of whole tree, and 3 644 kg of dead branches.

   (c) Where point sampling is being used, a modified Equation 1 will be employed with basal area per hectare (G, m^2) and mean height (h) of the stand. This modified ovendry mass formula, for each component, is $OM/ha=(40\,000 \cdot b_1/\pi) \cdot G \cdot h$. For example, a pure balsam fir stand with G=28.00 m^2/ha and h=18.50 m has 82 046 kg/ha of stem wood, 13 211 kg/ha of stem bark, 10 599 kg/ha of live branches, 14 892 kg/ha of twigs plus needles, 120 748 kg/ha of whole tree, and 4 729 kg/ha of dead branches.

2. Calculating ovendry mass of merchantable and unmerchantable components from inventory data

(a) Where tree dimensions are available and merchantability is defined by the merchantable top diameter, Equation 3 (Table 7) will be used with d and dm measurements of either individual trees or of the mean tree in order to find merchantability percentages. These percentages will then be applied to the ovendry mass of stem wood plus bark for computing component ovendry masses. For example, a balsam fir tree with d=21.4 cm and dm=10.0 cm contains 81.59% merchantable-stem wood, 12.43% merchantable-stem bark and 5.98% top wood plus bark. In terms of mass, for the tree given in 1(a), these are 96.1 kg, 14.6 kg, and 7.0 kg, respectively.

(b) Where tree dimensions are available and merchantability is defined by merchantable height, Equation 4 (Table 8) will be used with h and hm measurements of either individual trees or of the mean tree, as explained in 2(a). For example, a balsam fir tree with h=17.80 m and hm=12.00 m (that is, three 4-m logs) has 79.31% merchantable-stem wood, 11.70% merchantable-stem bark and 8.99% top wood plus bark. When converted to mass, for the tree given in 1(a), these are as follows: 93.3 kg, 13.8 kg and 10.6 kg.

However, as mentioned earlier, all of the above calculated merchantable-stem wood and merchantable-stem bark values contain stump wood and stump bark. This material should be subtracted in order to find the net merchantable values. That can be done either at the percentage level of the calculations or at the ovendry-mass level. Let us look at Example 2(a) again:

If in this example stump height is 15 cm, then ovendry mass at this height is 52.07% of the ovendry mass of the stump at 30-cm stump height (Table 10). For balsam fir, at 15-cm stump height, the ovendry mass of stump wood is 2.62% (=0.0503 x 0.5207) and of stump bark is 0.45% (=0.0087 x 0.5207) of the total stem wood plus bark (Table 11). Therefore, the final results would be as follows: stump wood 2.62%, net merchantable-stem wood 78.97%, stump bark 0.45%, net merchantable-stem bark 11.98%, and top wood plus bark 5.98%. In terms of mass these would be 3.1 kg, 93.0 kg, 0.5 kg, 14.1 kg, and 7.0 kg, respectively. Similar examples using balsam fir are also provided in Table 13.

Stump deductions given in Table 11 as an example for balsam fir are based on figures provided in Tables 9 and 10, and could be prepared for all other species in a similar manner.

Because of insufficient merchantable diameter and merchantable height data at the very top of stems, and due to the nature of quadratic equations, the use of Equations 3 and 4 are restricted. The permissible dm/d and hm/h ratios are given in Table 12.

3. Calculating ovendry mass of logging residues from inventory data

Logging residues contain unmerchantable top of the stem (wood and bark), live branches, and twigs and needles. Bark on the merchantable portion of the stem is assumed to be carried to the mill yard together with the merchantable-stem wood. Stump is assumed not to be removed for utilization. However, if we also include stump wood plus bark in the residues, and if the masses of unmerchantable top and stump are to be calculated using mass of total stem estimated by Equation 1, then the formula to be used for the mass of total logging residues will have the following form:

$$OM = d^2 h \cdot (a_1 + a_2 \cdot (a_3 + a_4 \cdot (dm/d) + a_5 \cdot (dm/d)^2 + k \cdot q)) \quad (5)$$

where the new coefficients are as follows:

$a_1 = b_1$ of live branches plus b_1 of twigs

and needles of Equation 1 (Table 2),

$a_2=b_1$ of stem wood plus b_1 of stem bark of Equation 1 (Table 2),

a_3, a_4, a_5 =respectively, b_0, b_1, b_2 of top wood plus bark of Equation 3 (Table 7), divided by 100.0,

k=percentage of stump wood plus bark (Table 10),

q=percentage of different stump heights (Table 11).

Whenever stump (wood and bark) is not included in the residues, then the term of $k \cdot q$ would be removed from Equation 5. Also, whenever the merchantability is defined by the merchantable height, the parameters a_3, a_4, and a_5 will be taken from Table 8.

For example, let us take the same tree given in Example 2 with a height of 17.80 m and a stump height of 15 cm. When calculated, logging residues including stump will be 42.1 kg and excluding stump, 38.5 kg. Subsequently, the net merchantable section (wood and bark) will have 149.2-42.1 = 107.1 kg of ovendry mass.

SUMMARY AND CONCLUSION

Equations for estimating biomass of single trees by major components are now available for ten softwood species of Ontario. These equations, based on diameter at breast height outside bark and total tree height, directly estimate the ovendry mass of trees larger than 5.0 cm of d. One equation is provided for all species for the whole-tree ovendry mass for trees with a d from 0.1 cm to 5.0 cm. Ovendry masses of seedlings and saplings equal to or shorter than 1.30 m of height are also given. The average wood densities can be used with the stem volume inside bark to estimate the mass of stem wood. The masses of the other components can then be found by using the component ratios. Also, whenever needed, converting green mass into ovendry mass can be done for each main tree-component by employing their appropriate ratios.

Equations for predicting ovendry mass percentages of merchantable and unmerchantable components of stem were also developed for the same tree species. These are based on merchantable top diameter and diameter at breast height outside bark, or merchantable height and total tree height. These equations are given together with stump deductions and with their permissible range of ratios of application. Computing ovendry mass in its absolute value requires having the ovendry mass of stem wood plus bark in kilograms (or pounds).

If dimensional single-tree data are not available, all the above equations can still be used, but applied to the diameter and height of a stand's mean tree.

The aforementioned findings are applicable to the same tree species growing elsewhere but under the same ecological conditions as Ontario.

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APPENDIX A

Tables 1-5 for the main-tree components

Table 1. Statistical data for trees of component-mass analysis

Species	Number of trees n*	d (cm)			h (m)			Whole tree GM (kg) §		
		Mean	SD†	Range	Mean	SD†	Range	Mean	SD†	Range
E. white pine	139	33.0	15.7	5.6 - 68.7	20.3	7.1	4.2 - 38.5	1118.2	1046.9	8.9 - 4447.9
Red pine	115	27.4	13.1	5.4 - 55.1	17.5	6.5	3.9 - 34.4	717.9	662.3	9.2 - 2852.2
Jack pine	75	16.3	3.9	8.8 - 26.8	17.6	2.8	11.9 - 23.5	183.5	121.3	28.2 - 627.5
Black spruce	74	11.0	3.7	5.2 - 22.2	11.6	3.1	3.8 - 18.9	73.0	61.0	7.6 - 347.8
White spruce	77	14.7	5.7	6.3 - 35.8	12.2	4.5	5.0 - 23.2	138.0	140.7	13.5 - 871.8
Balsam fir	66	13.1	4.5	5.7 - 27.4	12.9	3.3	6.8 - 19.2	114.5	111.1	9.5 - 652.3
Tamarack	79	18.0	7.8	5.1 - 33.8	17.6	5.6	6.5 - 26.7	288.4	243.6	10.1 - 909.4
E. white cedar	84	19.7	9.3	5.1 - 38.8	11.8	3.5	4.0 - 19.0	188.4	171.6	7.0 - 671.4
E. red cedar	26	14.5	7.8	5.1 - 38.2	7.8	2.3	4.5 - 12.8	117.1	127.2	5.9 - 523.3
E. hemlock	140	27.0	13.1	5.3 - 51.4	15.6	5.4	4.6 - 26.5	688.0	697.2	10.4 - 2978.8
All softwoods	875	21.7	12.9	5.1 - 68.7	15.5	6.1	3.8 - 38.5	472.3	675.9	5.9 - 4447.9

*Hereinafter n designates number of sample trees.

†Standard deviation.

§Green mass of tree above ground including stem, live branches, twigs and needles.

Table 2. Regression coefficients and statistics of Equation 1: $OM = b_1 \cdot d^2h$

Component	b_1	r^2	SEE%	Mean (kg)	Range (kg)
		Eastern white pine (n=139)			
Stem wood	0.010900	0.962	18.8	371.1	2.0 - 1646.2
Stem bark	0.001595	0.929	26.3	54.2	0.4 - 236.4
Live branches	0.002249	0.634	80.9	72.2	0.4 - 500.7
Twigs plus needles	0.000732	0.661	51.5	27.8	0.7 - 107.0
Whole tree	0.015476	0.970	16.6	525.3	3.8 - 2183.1
Dead branches*	0.000397	0.322	106.8	15.0	0.0 - 84.9
		Red pine (n=115)			
Stem wood	0.012713	0.957	22.3	246.3	1.9 - 1356.1
Stem bark	0.000969	0.873	33.9	20.4	0.4 - 96.9
Live branches	0.002417	0.520	82.8	51.5	0.4 - 281.8
Twigs plus needles	0.001048	0.302	69.5	26.8	1.1 - 80.8
Whole tree	0.017147	0.982	13.2	345.0	4.0 - 1572.6
Dead branches*	0.000416	0.235	118.0	9.8	0.0 - 68.2
		Jack pine (n=75)			
Stem wood	0.015865	0.982	8.3	83.5	14.9 - 260.8
Stem bark	0.001260	0.911	16.7	6.8	1.6 - 20.6
Live branches	0.000827	0.737	49.8	3.9	0.3 - 20.6
Twigs plus needles	0.001042	0.792	35.9	5.3	0.7 - 21.3
Whole tree	0.018994	0.982	8.4	99.5	17.7 - 320.4
Dead branches*	0.000756	0.191	114.5	4.1	0.2 - 31.0
		Black spruce (n=74)			
Stem wood	0.016625	0.981	12.1	30.2	2.1 - 163.7
Stem bark	0.001726	0.891	24.6	3.4	0.6 - 14.3
Live branches	0.001288	0.552	70.2	2.4	0.1 - 9.8
Twigs plus needles	0.003031	0.635	57.1	5.8	0.2 - 25.9
Whole tree	0.022670	0.974	13.6	41.8	4.5 - 213.2
Dead branches*	0.001367	0.461	79.6	2.6	0.0 - 12.0

Table 2. (cont'd)

Component	b_1	r^2	SEE%	Mean (kg)	Range (kg)
		White spruce (n=77)			
Stem wood	0.014027	0.993	10.1	53.5	3.5 - 412.8
Stem bark	0.001438	0.933	24.8	6.2	0.7 - 37.5
Live branches	0.001097	0.328	84.7	5.5	0.1 - 28.7
Twigs plus needles	0.001657	0.167	88.3	9.0	0.3 - 39.7
Whole tree	0.018219	0.967	19.1	74.2	8.1 - 500.7
Dead branches*	0.001012	0.810	51.6	4.1	0.1 - 29.9
		Balsam fir (n=66)			
Stem wood	0.012440	0.972	14.7	36.6	4.0 - 164.8
Stem bark	0.002003	0.938	24.6	5.6	0.6 - 28.8
Live branches	0.001607	0.619	105.8	3.7	0.2 - 48.4
Twigs plus needles	0.002258	0.761	65.6	5.7	0.3 - 51.9
Whole tree	0.018308	0.976	14.9	51.6	5.2 - 293.8
Dead branches*	0.000717	0.392	85.0	2.3	0.2 - 13.8
		Tamarack (n=79)			
Stem wood	0.015688	0.965	15.4	128.7	2.4 - 388.1
Stem bark	0.001297	0.882	29.2	10.7	0.4 - 37.9
Live branches	0.001390	0.545	86.3	10.8	0.1 - 65.5
Twigs plus needles	0.000998	0.711	47.8	8.4	0.4 - 26.6
Whole tree	0.019373	0.957	17.3	158.6	4.4 - 469.2
Dead branches*	0.000118	0.931	164.7	1.1	0.0 - 10.3
		Eastern white cedar (n=84)			
Stem wood	0.008894	0.908	26.7	63.4	1.5 - 222.8
Stem bark	0.001113	0.849	34.9	8.0	0.4 - 26.3
Live branches	0.002469	0.686	72.4	15.7	0.3 - 124.5
Twigs plus needles	0.001766	0.812	47.3	11.7	0.6 - 65.3
Whole tree	0.014242	0.943	22.0	98.8	3.7 - 350.4
Dead branches*	0.000420	0.259	97.4	3.4	0.6 - 21.2

Table 2. (cont'd)

Component	b_1	r^2	SEE%	Mean (kg)	Range (kg)
		Eastern red cedar (n=26)			
Stem wood	0.012166	0.962	21.9	32.9	2.2 - 166.8
Stem bark	0.001021	0.757	44.4	3.2	0.3 - 11.7
Live branches	0.007203	0.761	69.5	18.2	0.1 - 86.8
Twigs plus needles	0.003803	0.666	65.8	11.2	0.3 - 51.1
Whole tree	0.024193	0.922	31.9	65.5	3.1 - 316.4
Dead branches*	0.001650	0.512	100.2	4.6	0.0 - 24.2
		Eastern hemlock (n=140)			
Stem wood	0.013240	0.941	25.6	222.8	2.6 - 1167.7
Stem bark	0.002293	0.867	36.7	40.4	0.5 - 192.0
Live branches	0.003096	0.658	75.1	51.7	0.1 - 377.0
Twigs plus needles	0.001320	0.722	52.6	24.3	0.8 - 91.0
Whole tree	0.019949	0.940	25.4	339.2	5.2 - 1532.7
Dead branches*	0.000606	0.328	94.9	12.2	0.0 - 85.3
		All softwoods (n=875)			
Stem wood	0.011718	0.952	31.4	162.9	1.5 - 1646.2
Stem bark	0.001580	0.855	60.0	21.4	0.3 - 236.4
Live branches	0.002393	0.672	109.2	30.8	0.1 - 500.7
Twigs plus needles	0.000918	0.575	78.5	16.2	0.2 - 107.0
Whole tree	0.016609	0.958	29.1	231.3	3.1 - 2183.1
Dead branches*	0.000437	0.383	130.8	7.3	0.0 - 85.3

*Ovendry mass of dead branches is not included in the whole-tree ovendry mass.

Table 3. Component, whole-tree, and dead-branches ovendry mass as percent of stem wood ovendry mass

Component	E. white pine (n=139)	Red pine (n=115)	Jack pine (n=75)	Black spruce (n=74)	White spruce (n=77)	Balsam fir (n=66)	Tamarack (n=79)	E. white cedar (n=84)	E. red cedar (n=26)	E. hemlock (n=140)	All softwoods (n=875)
Stem bark	14.6	7.6	7.9	10.4	10.3	16.1	8.3	12.5	8.4	17.3	13.5
Live branches	20.6	19.0	5.2	7.8	7.8	12.9	8.8	27.8	59.2	23.4	20.4
Twigs plus needles	6.7	8.2	6.6	18.2	11.8	18.2	6.4	19.8	31.3	10.0	7.8
Whole tree	141.9	134.8	119.7	136.4	129.9	147.2	123.5	160.1	198.9	150.7	141.7
Dead branches*	3.6	3.3	4.8	8.2	7.2	5.8	7.5	4.7	13.6	4.6	3.7

*Ovendry mass of dead branches is not included in the whole-tree ovendry mass.

Table 4. Ovendry mass/green mass ratios

Component	E. white pine (n=139)	Red pine (n=115)	Jack pine (n=75)	Black spruce (n=74)	White spruce (n=77)	Balsam fir (n=66)	Tamar-ack (n=79)	E. white cedar (n=84)	E. red cedar (n=26)	E. hem-lock (n=140)	All soft-woods (n=875)
Stem wood	0.459	0.478	0.563	0.615	0.561	0.442	0.577	0.535	0.584	0.478	0.485
Stem bark	0.552	0.502	0.473	0.477	0.469	0.473	0.428	0.501	0.472	0.594	0.540
Live branches	0.486	0.506	0.453	0.557	0.555	0.509	0.537	0.559	0.600	0.525	0.508
Twigs plus needles	0.444	0.446	0.439	0.464	0.461	0.456	0.416	0.454	0.472	0.442	0.445
Whole tree	0.470	0.481	0.542	0.573	0.538	0.451	0.550	0.524	0.559	0.493	0.490

Table 5. Average basic wood densities

Species	Basic wood density (kg/m^3)		Number of sample trees		Number of specimens*
Eastern white pine	340	(364)	145	(25)†	548
Red pine	376	(392)	123	(25)	445
Jack pine	412	(421)	75	(25)	291
Black spruce	442	(406)	74	(32)	229
White spruce	386	(354)	77	(43)	265
Balsam fir	349	(335)	66	(26)	222
Tamarack	484	(485)	94	(11)	312
Eastern white cedar	328	(299)	97	(19)	330
Eastern red cedar	446	-	35	-	101
Eastern hemlock	410	(404)	155	(31)	559
All softwoods	391	-	941	-	3302

*Number of wedges taken from the disks (one from each disk) in order to determine basic wood density.

†Figures in parentheses are from Jessome 1977.

APPENDIX B

Tables 6-13 for the merchantable and unmerchantable components of the stem

Table 6. Statistical data for trees of merchantable-mass analysis

Species	Number of trees n	Number of observations	d (cm)		h (m)		dm/d		hm/h	
			Mean	Range	Mean	Range	Mean	Range	Mean	Range
E. white pine	131	393	34.6	9.9 - 68.7	21.23	5.40 - 38.50	0.615	0.131 - 0.992	0.537	0.103 - 0.956
Red pine	104	312	29.5	10.3 - 55.1	18.71	7.10 - 34.35	0.624	0.161 - 0.992	0.518	0.098 - 0.931
Jack pine	72	216	16.6	10.2 - 26.8	17.81	11.90 - 23.50	0.735	0.336 - 0.990	0.429	0.088 - 0.847
Black spruce	42	126	13.6	10.0 - 22.2	13.54	9.10 - 18.90	0.818	0.405 - 0.991	0.352	0.079 - 0.773
White spruce	58	174	16.8	10.4 - 35.8	13.93	6.20 - 23.20	0.755	0.251 - 0.991	0.413	0.096 - 0.862
Balsam fir	46	138	15.1	10.0 - 27.4	14.54	8.00 - 19.20	0.784	0.329 - 0.992	0.384	0.081 - 0.781
Tamarack	62	186	20.8	10.3 - 33.8	19.84	11.05 - 26.70	0.697	0.243 - 0.991	0.466	0.108 - 0.892
E. white cedar	67	201	22.7	10.2 - 38.8	13.07	8.30 - 19.00	0.668	0.219 - 0.992	0.458	0.102 - 0.850
E. red cedar	16	48	18.6	10.8 - 38.2	9.19	6.30 - 12.75	0.748	0.259 - 0.992	0.383	0.127 - 0.735
E. hemlock	124	372	29.2	10.2 - 51.4	16.59	5.17 - 26.50	0.647	0.066 - 0.993	0.498	0.111 - 0.901
All softwoods	722	2166	24.6	9.9 - 68.7	17.13	5.17 - 38.50	0.682	0.066 - 0.993	0.469	0.079 - 0.956

Table 7. Regression coefficients and statistics of Equation 3: $OM\% = b_0 + b_1 \cdot (dm/d) + b_2 \cdot (dm/d)^2$

Component	Regression coefficients b_0	b_1	b_2	R^2	SEE%	Mean (%)	Range (%)
			Eastern white pine (n=131)				
Merchantable-stem wood	80.214	54.807	-108.398	0.872	9.8	66.3	21.6 - 91.8
Merchantable-stem bark	11.417	10.066	-17.046	0.565	20.2	10.1	3.5 - 19.7
Top wood plus bark	8.369	-64.873	125.444	0.886	29.3	23.6	0.2 - 72.7
			Red pine (n=104)				
Merchantable-stem wood	81.475	74.539	-134.194	0.896	9.1	68.8	17.0 - 95.7
Merchantable-stem bark	7.314	5.095	-9.611	0.402	26.7	6.3	1.9 - 12.7
Top wood plus bark	11.211	-79.634	143.805	0.899	26.6	24.9	0.1 - 80.1
			Jack pine (n=72)				
Merchantable-stem wood	69.383	120.937	-171.664	0.931	8.4	61.3	18.0 - 92.3
Merchantable-stem bark	4.143	13.336	-15.203	0.630	18.3	5.4	1.8 - 8.9
Top wood plus bark	26.474	-134.273	186.867	0.933	16.2	33.3	1.4 - 79.4
			Black spruce (n=42)				
Merchantable-stem wood	40.410	191.766	-209.326	0.918	10.1	53.3	17.3 - 89.0
Merchantable-stem bark	2.046	24.044	-23.326	0.714	18.4	5.7	2.4 - 10.0
Top wood plus bark	57.544	-215.810	232.652	0.919	14.3	41.0	3.6 - 80.0
			White spruce (n=58)				
Merchantable-stem wood	70.282	103.401	-148.077	0.948	7.2	59.6	21.3 - 85.6
Merchantable-stem bark	5.835	17.202	-19.792	0.634	20.6	7.0	2.2 - 16.2
Top wood plus bark	23.883	-120.603	167.869	0.946	14.4	33.4	1.8 - 75.9
			Balsam fir (n=46)				
Merchantable-stem wood	46.841	160.823	-185.023	0.909	10.0	54.8	21.2 - 90.9
Merchantable-stem bark	11.463	11.381	-19.944	0.780	19.2	7.6	2.9 - 13.7
Top wood plus bark	41.696	-172.204	204.967	0.922	15.6	37.6	0.9 - 75.8

Table 7. (cont'd)

Component	Regression coefficients b_0	b_1	b_2	R^2	SEE%	Mean (%)	Range (%)
			Tamarack (n=62)				
Merchantable-stem wood	68.161	123.771	-167.127	0.860	11.0	67.0	26.0 - 93.2
Merchantable-stem bark	6.547	6.959	-11.666	0.408	36.1	5.3	1.6 - 19.2
Top wood plus bark	25.292	-130.730	178.793	0.862	28.6	27.7	0.6 - 71.8
			Eastern white cedar (n=67)				
Merchantable-stem wood	77.362	68.986	-123.855	0.902	9.5	62.8	20.5 - 90.7
Merchantable-stem bark	9.862	6.344	-13.495	0.586	24.9	7.5	1.6 - 16.5
Top wood plus bark	12.776	-75.330	137.350	0.903	22.4	29.7	1.1 - 77.3
			Eastern red cedar (n=16)				
Merchantable-stem wood	78.781	69.528	-115.054	0.890	10.9	61.5	28.0 - 92.2
Merchantable-stem bark	5.164	14.407	-16.919	0.742	19.9	5.7	2.6 - 11.4
Top wood plus bark	16.055	-83.935	131.973	0.896	21.8	32.8	1.5 - 69.4
			Eastern hemlock (n=124)				
Merchantable-stem wood	74.025	66.398	-114.163	0.876	10.2	62.5	19.5 - 90.2
Merchantable-stem bark	14.101	12.174	-21.177	0.529	25.1	11.9	3.8 - 28.4
Top wood plus bark	11.874	-78.572	135.340	0.885	28.2	25.6	0.2 - 76.3
			All softwoods (n=722)				
Merchantable-stem wood	75.405	81.546	-132.194	0.882	10.5	63.1	17.0 - 95.7
Merchantable-stem bark	12.043	1.422	-9.824	0.378	37.4	8.0	1.6 - 28.4
Top wood plus bark	12.552	-82.968	142.018	0.898	23.8	28.9	0.1 - 80.1

Table 8. Regression coefficients and statistics of Equation 4: $OM\% = b_0 + b_1 \cdot (hm/h) + b_2 \cdot (hm/h)^2$

Components*	Regression coefficients b_0	b_1	b_2	R^2	SEE%
		Eastern white pine (n=131)			
Merchantable-stem wood	3.058	178.703	-95.055	0.969	4.8
Merchantable-stem bark	1.491	24.504	-13.158	0.609	19.2
Top wood plus bark	95.451	-203.207	108.213	0.981	11.9
		Red pine (n=104)			
Merchantable-stem wood	3.987	185.036	-96.638	0.971	4.8
Merchantable-stem bark	1.002	16.237	-9.835	0.402	26.7
Top wood plus bark	95.011	-201.273	106.473	0.968	14.9
		Jack pine (n=72)			
Merchantable-stem wood	5.985	172.893	-84.215	0.981	4.4
Merchantable-stem bark	1.266	13.730	-8.046	0.662	17.4
Top wood plus bark	92.749	-186.623	92.261	0.983	8.1
		Black spruce (n=42)			
Merchantable-stem wood	6.454	168.476	-80.093	0.951	7.8
Merchantable-stem bark	0.831	18.755	-11.461	0.779	16.2
Top wood plus bark	92.715	-187.231	91.554	0.956	10.5
		White spruce (n=58)			
Merchantable-stem wood	6.990	171.956	-88.106	0.975	5.0
Merchantable-stem bark	0.737	22.026	-13.753	0.689	19.1
Top wood plus bark	92.273	-193.982	101.859	0.978	9.2
		Balsam fir (n=46)			
Merchantable-stem wood	6.651	166.650	-87.306	0.954	7.2
Merchantable-stem bark	0.805	21.737	-8.266	0.787	18.9
Top wood plus bark	92.544	-188.387	95.572	0.962	10.8

Table 8. (cont'd)

Components*	Regression coefficients b_0	b_1	b_2	R^2	SEE%
		Tamarack (n=62)			
Merchantable-stem wood	4.192	196.226	-109.908	0.947	6.8
Merchantable-stem bark	0.215	16.105	-9.305	0.372	37.1
Top wood plus bark	95.593	-212.331	119.213	0.935	19.6
		Eastern white cedar (n=67)			
Merchantable-stem wood	5.512	176.344	-92.736	0.947	7.0
Merchantable-stem bark	0.314	22.065	-11.568	0.650	22.9
Top wood plus bark	94.174	-198.409	104.304	0.953	15.5
		Eastern red cedar (n=16)			
Merchantable-stem wood	4.807	199.553	-112.434	0.910	9.8
Merchantable-stem bark	-0.042	20.328	-11.356	0.764	19.1
Top wood plus bark	95.235	-219.881	123.790	0.918	19.3
		Eastern hemlock (n=124)			
Merchantable-stem wood	3.718	173.047	-92.219	0.944	6.8
Merchantable-stem bark	-0.248	37.785	-22.564	0.580	23.7
Top wood plus bark	96.530	-210.832	114.783	0.956	17.4
		All softwoods (n=722)			
Merchantable-stem wood	4.785	178.845	-95.276	0.948	7.0
Merchantable-stem bark	0.933	20.714	-10.010	0.397	36.8
Top wood plus bark	94.282	-199.559	105.286	0.964	14.0

*Mean values and ranges of these components are the same as those provided in Table 7.

Table 9. Average stump values at 30-cm stump height, as percent of the total stem mass

Species	Number of trees n	Mean value			Stump wood plus bark	
		Stump wood	Stump bark	Stump wood plus bark	SD*	SE*
Eastern white pine	131	4.31	0.95	5.26	1.959	0.099
Red pine	104	4.52	0.74	5.26	1.930	0.109
Jack pine	72	4.19	0.83	5.02	0.802	0.055
Black spruce	42	5.66	0.78	6.44	1.412	0.126
White spruce	58	5.90	0.82	6.72	2.110	0.160
Balsam fir	46	5.03	0.87	5.90	1.874	0.160
Tamarack	62	4.67	0.44	5.11	1.293	0.095
Eastern white cedar	67	7.52	0.83	8.35	1.917	0.135
Eastern red cedar	16	9.77	0.80	10.57	2.398	0.346
Eastern hemlock	124	4.98	0.99	5.97	1.733	0.090
All softwoods	722	5.14	0.83	5.97	2.118	0.045

*SD = standard deviation; SE = standard error of the mean.

Table 10. Volume (and mass) percentages at different stump heights in relation to stump volume at 30 cm

Stump height (cm)	%
5	17.95
10	35.28
15	52.07
20	68.36
25	84.45
30	100.00

Table 11. Deduction percentages of stump wood mass and stump bark mass at different stump heights in total stem mass (wood plus bark): an example using balsam fir

Stump height (cm)	Stump wood (%)	Stump bark (%)	Stump wood plus bark (%)
5	0.90	0.16	1.06
10	1.77	0.31	2.08
15	2.62	0.45	3.07
20	3.44	0.59	4.03
25	4.25	0.73	4.98
30	5.03	0.87	5.90

Table 12. Permissible ratios for Equations 3 and 4

Species	Equation 3	Equation 4
	Smallest permitted dm/d	Largest permitted hm/h
Eastern white pine	0.271*	0.939
Red pine	0.277	0.913
Jack pine	0.359	0.879
Black spruce	0.464	0.860
White spruce	0.359	0.924
Balsam fir	0.420	0.930
Tamarack	0.366	0.891
Eastern white cedar	0.274	0.910
Eastern red cedar	0.318	0.749
Eastern hemlock	0.290	0.869
All softwoods	0.292	0.896

*A dm/d ratio of 0.271 means, for example, 7/25.8, 8/29.5, 9/33.2 and 10/36.9, and a value such as 0.100 is not realistic for the species studied.

Table 13. Percentage distribution of stump, merchantable part and top of the stem by various stump heights for balsam fir using Equation 3

dm/d	Stump height (cm)	Stump wood	Stump bark	Net merchant-able-stem wood	Net merchant-able-stem bark	Top wood plus bark	Total
		% of total stem ovendry mass					
0.40	10	1.77	0.31	79.80	12.51	5.61	100.00
	20	3.44	0.59	78.13	12.23	5.61	100.00
	30	5.03	0.87	76.54	11.95	5.61	100.00
0.65	10	1.77	0.31	71.43	10.12	16.37	100.00
	20	3.44	0.59	69.76	9.84	16.37	100.00
	30	5.03	0.87	68.17	9.56	16.37	100.00
0.90	10	1.77	0.31	39.94	5.24	52.74	100.00
	20	3.44	0.59	38.27	4.96	52.74	100.00
	30	5.03	0.87	36.68	4.68	52.74	100.00